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NON-LINEAR GENERATION OF ACOUSTIC NOISE IN THE I.A.R. SPACECRAFT CHAMBER BY MANUAL OR AUTOMATIC CONTROL*

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ABSTRACT

The requirement to produce high level acoustic noise fields with increasing accuracy in environmental test facilities dictates that a more precise understanding is required of the factors controlling non-linear noise generation.

This paper gives details of various non-linear effects found in acoustic performance data taken from the I.A.R. Spacecraft Acoustic Chamber. This type of data has enabled the I.A.R. to test large spacecraft to relatively tight acoustic tolerances over a wide frequency range using manually set controls.

An analog random-noise automatic control system was available and modified to provide automatic selection of the chamber's spectral sound pressure levels. The automatic control system when used to complete a typical qualification test appeared to equal the accuracy of the manual system and had the added advantage that parallel spectra could be easily achieved during preset tests.

INTRODUCTION

The Institute for Aerospace Research (I.A.R.) of the National Research Council, Canada, operates a spacecraft acoustic test chamber for aerospace research and development at the Aeroacoustic Facility (ref. 1) of the Structures and Materials Laboratory.

The spacecraft chamber has been required to generate high level acoustic noise fields with increasing spectral accuracy to simulate rocket and aeroengine noise for qualification testing of aerospace structures and equipment. In the future it is likely that this trend will continue and therefore: acoustic test sound level spectra may need to be controlled to accuracies of $\pm$ 1 dB; the spectra may be defined in finer bands than the 1/3 or 1/1 octave bands at present in use; sound level tolerances at low and high frequencies may be tightened to match those at mid frequencies; exploratory tests at progressively higher levels may be restricted to one relatively low level test, e.g. -10 dB, for expensive spacecraft.

Complications to the production of accurate acoustic levels for spacecraft tests are that the generation process is highly non-linear and not easily predicted, and that the acoustic absorption and insertion effects of a large spacecraft are not accurately known in advance of the spacecraft being placed and tested in the chamber. The short duration of a spacecraft acoustic test will usually preclude any manual readjustments of the generators' controls being made during the test. Although spectral level test requirements cover the range of frequencies from 20 Hz to 10 kHz, it should be noted that presently available commercial electro-pneumatic noise generators may only have direct control in the nominal frequency ranges of up to 500 Hz for 30 kW generators, and up to1,250 Hz for 10 kW generators.

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The remainder of the spectral levels in the higher frequency ranges have to be filled by non-linear harmonics from lower frequency inputs and by auxiliary aerodynamic (ref 2) or loudspeaker noise sources (ref 3).

It is therefore essential for accurate manual control and for the design of automatic control systems that quantitative data be assembled of the effects of the main control parameters (electrical current and gas pressure) on the non-linear acoustic performances. The main purpose of this paper is to illustrate some of these non-linear effects by presenting performance data from a 30 kW type generator that was connected to the I.A.R. Spacecraft Chamber by a 32 Hz horn and which was being used to produce qualification test spectrum at overall levels of 146.6 dB for Ariane or Space Shuttle type launches.

The I.A.R. Spacecraft Chamber has floor dimensions of 9.75 m (32.0 ft) x 6.9 m (22.6 ft) and a height of 8.0 m (26.2 ft) giving a total internal volume of about 540 m3 (19,000 ft3). A side view of the chamber with its complement of three 30 Kw, one 10 kW and four N.A.E. aerodynamic generators connected to 25, 32, 100 and 200 Hz horns is shown in figure 1.

SYMBOLS

I	r.m.s. of electrical current supplied to generator	(amp)
IdB	20 log $_{10}$(I), electrical current level	(ref 1 amp)
P	air pressure supplied to generator	(p.s.i.g.)
dB	1/3 octave sound pressure level	(ref 20 μPa)
O.A.S.P.L.	overall sound pressure level (25 Hz - 10 kHz)	(ref 20 μPa)

ACOUSTIC PERFORMANCE TESTS (MANUAL CONTROL)

Manual Control System

The noise generator's control system is illustrated in figure 2. The manual control system consisted of an electrical random noise generator which supplied spectrally shaped drive current to the armature of the electro-pneumatic generator. The drive current spectrum was shaped over the frequency range of 25 to 630 Hz by fifteen adjustable 1/3 octave filters located in the equaliser unit. The overall current, (I), was adjusted to the required level by the gain on the audio power amplifier. Compressed air was supplied at selectable pressures, (P), to the generator and in most of the tests described here was held constant at 30 or 10 p.s.i.g. The acoustic sound pressure level spectrum in the chamber was measured by an array of six 1/2-in. diameter pressure response condenser microphones and the averaged spectrum was displayed and recorded on a 1/3 octave real time analyser.

Preliminary Set-up

In a preliminary experiment, to meet the representative spacecraft qualification tolerances over the 25-500 Hz range, the air supply pressure was set to 30 p.s.i.g. and the gains of the power amplifier and the fifteen equaliser filters were adjusted until the sound level spectrum in the chamber was as close as practicable to the mean spectrum between the two tolerance lines for the frequency range of 25 to 500 Hz. The drive current which best met this mean spectrum occurred at 18.5 IdB, although it will be noted in figure 3 that the spectrum and the overall level tolerances can be met over a wider range of frequencies when the current is increased to 20 and 21 IdB. The 18.5 IdB setting was used as a reference in the following tests.

Variation of Sound Spectra Levels with Drive Current (30 p.s.i.g.)

The air supply was selected at a fixed value of 30 p.s.i.g. and sound level spectra were recorded for a series of drive current levels. Figure 4 shows selected spectra over the drive current range of 0 to 21 IdB with the corresponding overall sound levels increasing from 122 dB to 148 dB. An important feature to note, in addition to the effect of increased current on overall levels, is that the spectral slopes at frequencies below the maxima levels become more steep while slopes at frequencies greater than the maxima levels become less steep with increase of current. This non-linear effect on spectral shapes must be taken into account if the spectral shape is set during a preliminary spacecraft test at lower levels, e.g. at -10 dB or -5 dB. The asymptotic value of about 111 dB which is reached at frequencies between 1 kHz and 10 kHz, when the drive current is reduced below 9 IdB, is due to the residual noise of air flowing through the noise generator at 30 p.s.i.g.

The sound pressure levels in each 1/3 octave band and the overall level are plotted against the current level in figure 5. These curves are valuable for predicting sound level spectra at any selected drive current and for anticipating areas in which spectral control may be difficult. Distinct characteristics are recognisable in the set of frequency band levels up to 630 Hz which are directly controllable by the equaliser and in the set of frequency band levels above 630 Hz which are related to harmonic distortions. The modulator residual airflow noise also makes significant contributions to the levels for frequencies below 630 Hz and for the overall level when the current falls below 6 IdB. A general characteristic is that the slopes of the sound pressure level curves increase with increase of frequency and decrease with increase of current. Typical slopes range from 1 dB/IdB for the 25 Hz band to 2 dB/IdB for the 400 Hz band, while the overall level has a slope of approximately 2 dB/IdB at 10 IdB and 0.9 dB/IdB at 20 IdB. A current level increase of 6.5 IdB would be required in this case to raise the overall level by 10 dB from a 136 dB pretest low level to the target qualification level of 146 dB overall.

Variation of Sound Spectra Levels with Air Pressure (18.5 Idb)

The air pressure to the noise generator was set at a series of values between 30 p.s.i.g. and 5 p.s.i.g. while the drive current remained at the qualification level of 18.5 IdB. Typical spectral levels are shown in figure 6. The effect of decreasing the drive air pressure was to progressively decrease the overall sound pressure level from 145.8 to 138.4 dB and to steepen the slopes of the spectra levels on either side of the maxima which occured at 400 and 500 Hz. The sound pressure levels in each frequency band are plotted against air pressure in figure 8. As the air pressure is reduced from 30 to 5 p.s.i.g., the sound pressure levels for the 1/3 octave frequency bands of 25, 500 and 10,000 Hz fall 9.5, 4.5 and 16 dB respectively . It will be noted that the overall sound pressure falls only 1.9 dB as the air pressure is reduced to 15 p.s.i.g. and therefore a significant saving can be made in compressed air flow requirements in cases where a trade off is posssible between higher drive current and lower air pressure. In some cases it may be advantageous to run the generators at lower pressure when spectra with steeper slopes on either side of the maxima are required or because more linear response characteristics are needed for more accurate performance predictions. To illustrate this a new set of sound level spectra were recorded for various drive currents with the supply air pressure set at 10 p.s.i.g.

Variations of Sound Spectra Levels with Drive Current (10 p.s.i.g.)

Sound level spectra with the generator's air pressure set at 10 p.s.i.g. were repeated for a series of drive currents. Typical spectra for a range of drive current levels from -5 IdB to 21 IdB are plotted in figure 7 and detailed plots of the 1/3 octave and overall levels are plotted against current level in figure 9. The most significant change in performance when comparing figure 9 (10 p.s.i.g.) with figure 5 (30 p.s.i.g.) is that, over the direct control frequency range of 25 to 630 Hz, the slopes of the sound pressure level curves are close to 1 dB/IdB for the 10 p.s.i.g. and therefore in this frequency range spectral shapes are much less sensitive to current level changes than those found at 30 p.s.i.g. In the case of sound pressure levels at frequencies of 800 Hz and higher, it will be seen that the slopes are greater, but are similar to those found at 30 p.s.i.g. for the higher frequency range. The airflow generated background noise effects are now lowered to approximately 99 dB for the highest frequencies and are only marginally detectable in the lower frequency range between 50 and 25 Hz. It will be noted that the overall levels are 143 dB at 20 IdB and 132 dB at 8 IdB for an air pressure of 10 p.s.i.g. (figure 9), but corresponding levels in the 30 p.s.i.g case (figure 5) are 147.5 and 128.5 dB respectively.

When comparing overall sound pressure levels at 10 p.s.i.g. with those at 30 p.s.i.g. it will be noted that, for current levels above 12 IdB, the overall sound pressure levels for 30 p.s.i.g. are greater, whereas below 12 IdB those for the 10 p.s.i.g. case are greater. This explains the anomaly that with certain selected lower drive currents the overall level and some 1/3 octave levels will decrease as the drive pressure is increased.

ACOUSTIC PERFORMANCE TEST (AUTOMATIC CONTROL)

Automatic Control System

An analog random-noise vibration automatic control system that is no longer in production was added to the generator system, as shown in figure 2, with the object of reducing the pretest time involved in accurate manual testing and in compensating for spacecraft acoustic absorption.

A target spectrum is preselected on the control unit's equaliser and the automatic controller adjusts the drive current until the spectrum levels in the test chamber match the target spectrum levels. The technique for switching from a preset acoustic level to a test acoustic level differs from the vibration technique because of the non-linear effects in acoustic generation. The acoustic technique achieves a step increase of acoustic levels by decreasing the gain of the microphone amplifier signal by an amount exactly equal to the required increase. At the same time the gain of the controller's amplifier may be increased by an amount that would not allow acoustic spectral levels to overshoot. (The maximum allowable control gain increase may be assessed from the performance curves for the appropriate air supply presssure; e.g. figure 5 gives 6.5 IdB for an overall level increase from 136.6 to 146.6 dB).

Set-up Procedure

The generator's air supply was set to a pressure of 30 p.s.i.g. and the controller's equalisers in the frequency bands between 25 and 600 Hz were adjusted until the empty chamber's sound pressure levels spectrum met the qualification launch spectrum tolerance as shown in figure 10. This qualification level was met with the microphone amplifier attenuation set to 20 dB.

Variation of Sound Spectra Levels with Selected Levels

Various gains (microphone attenuation settings) were selected over the range of 0 dB to 23 dB and the acoustic spectra recorded after steady conditions had been reached on the analyser. A selection of achieved spectra are shown in figure 11. The overall and 1/3 octave band levels have been plotted against the selected gain in figure 12. It will be noted in the latter figure that the 1/3 octave levels for 80 to 500 Hz are parallel and increase accurately with a slope of 1 dB/dB. Therefore the automatic controller has an advantage over the manual control system in that pretest and test acoustic levels can be set up accurately with the same spectral shape and that non-linear and spacecraft absorption effects can be corrected.

COMPARISON OF AUTOMATIC CONTROL WITH MANUAL CONTROL FOR QUALIFICATION TEST WITH -10 dB PRETEST

Automatic Control Pretest (-10 db) and Qualification Test

The compressed air supply to the generator was adjusted to 30 p.s.i.g. with the relative humidity in the chamber stabilising at 2 % with an ambient temperature of 22° C ± 2° C. The automatic control system with its equaliser target spectrum as previously set up was switched on with the pretest gain setting of 10 dB. The 1/3 octave real time analyser was selected with a 4 sec. exponential averaging time and a sampling rate of 2 per sec. The qualification test level was selected by switching the controller gain to 20 dB at a time of 20 sec. The generator was switched off at a time of 70 sec. The time histories of the overall and selected 1/3 octave sound pressure levels are given in figure 13 with the achieved qualification test spectrum and tolerances being shown in figure 15.

Manual Pretest (-10 db) and Qualification Test

The manual control equaliser settings remained as set for all the previous manual tests.

The air pressure, the chamber ambient conditions and the analyser settings remained as in the above automatic control test. The power amplifier was adjusted to provide an overall level of 136.6 dB for 20 sec. before being readjusted to the setting which gave an overall level of 146.6 dB. The generator was then switched off at a time of 70 sec. The time histories of the overall level and selected 1/3 octave levels are plotted in figure 14 with the achieved qualification test spectrum and tolerances being shown in figure 16.

CONCLUSIONS

Details are contained of the non-linear acoustic performance of the I.A.R. Spacecraft Acoustic Chamber while it was being driven by a 30 kW electro-pneumatic generator and a 32 Hz horn using a manual control system to provide qualification and pretest acoustic spectra levels to simulate typical rocket launch noise. This type of performance data becomes increasingly important as tighter test tolerances require the development of more accurate test methods. The acoustic performance became more linear when the noise generator's air pressure was reduced from 30 p.s.i.g. to 10 p.s.i.g..

The second part of this paper reports on the performance of an analogue random noise vibration automatic control system which was adapted to cater for the non-linear characteristics of the noise generators. This automatic control system proved itself capable of matching the spectral accuracy of the manual control system during a typical qualification test and is likely to demonstrate considerable saving in time when testing spacecraft with large acoustic absorptions or when the pretests require the same spectral shape to be produced at lower levels.

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3. Hieken, M.H.; Levo, R.W. A High Intensity Reverberant AcousticTest Facility. Proceedings of the 34th Annual Technical Meeting of the Institute of Environmental Sciences, King of Prussia,Pennsylvania, May 3-5, 1988, pp. 131-135.

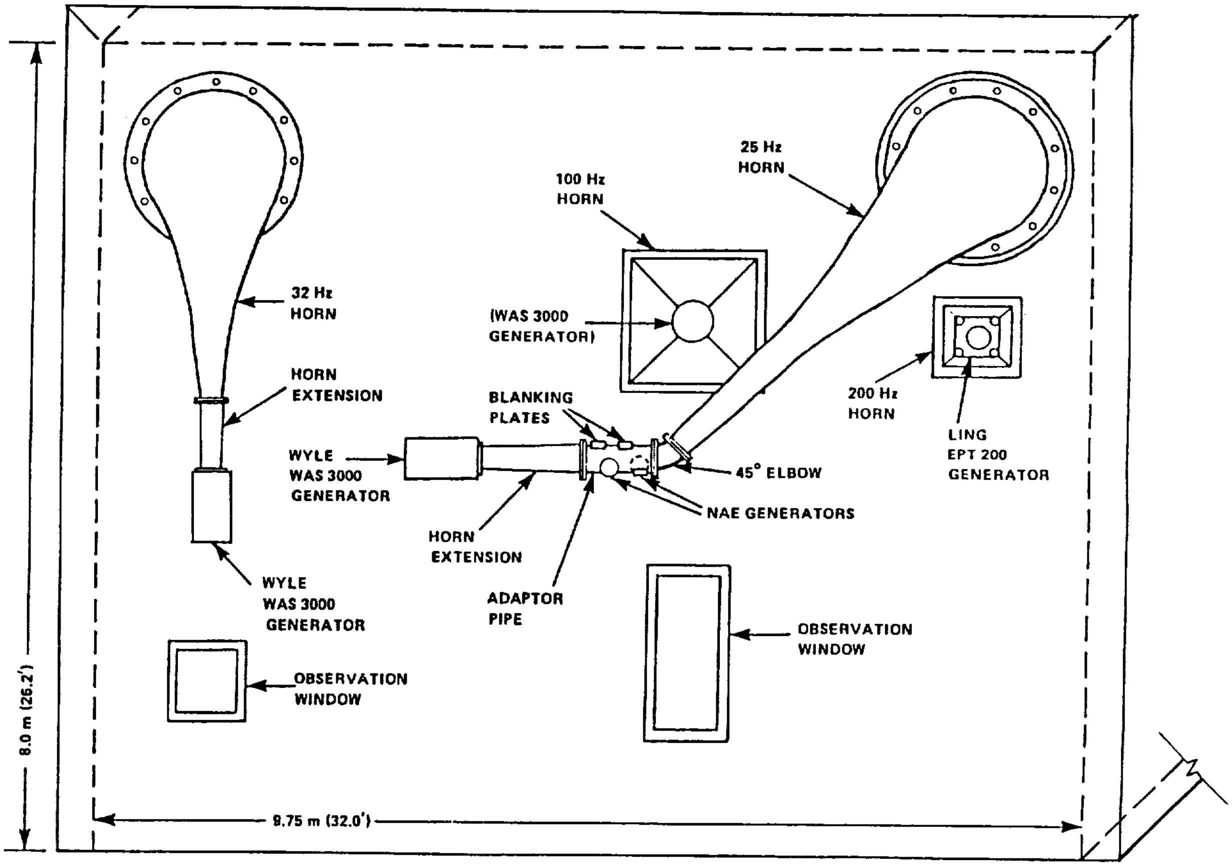

FIG. 1: SIDE VIEW OF NAE SPACECRAFT ACOUSTIC CHAMBER AND GENERATORS

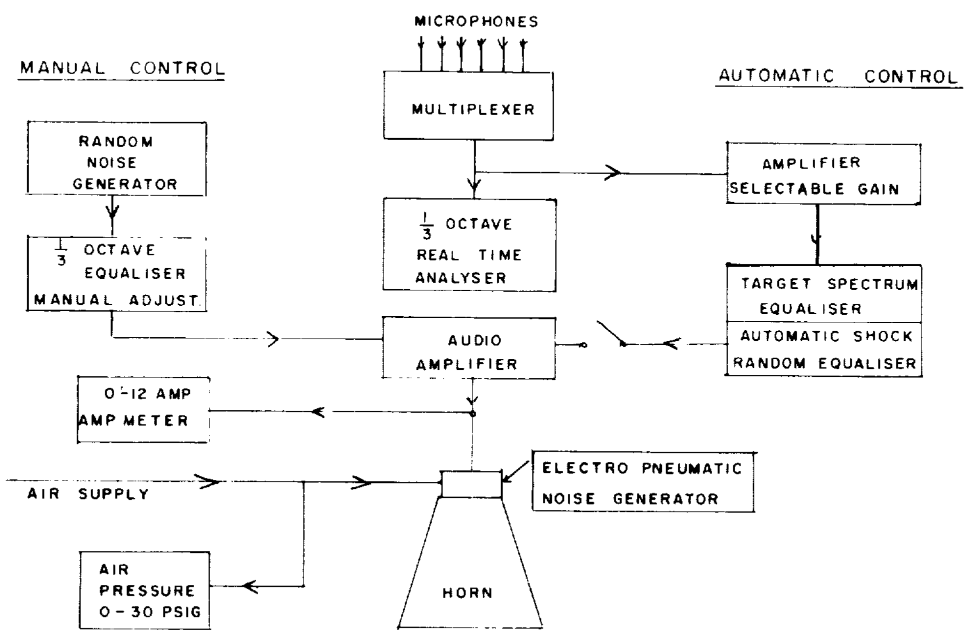

FIG. 2: NOISE GENERATOR CONTROL SYSTEM

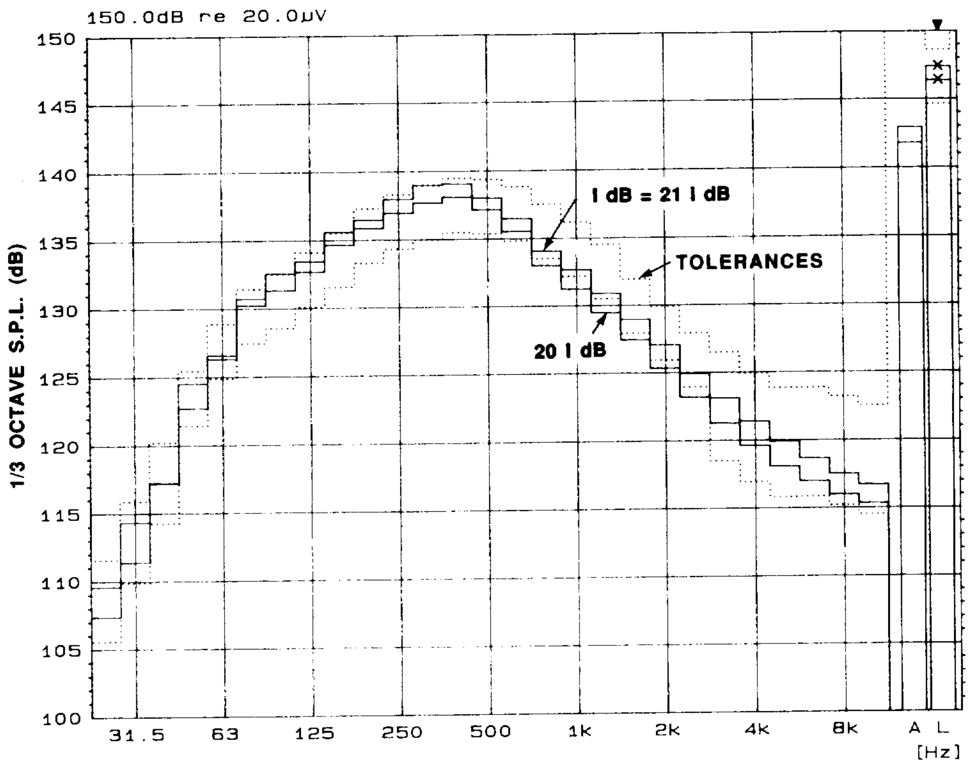

FIG. 3: QUAL. LAUNCH SPECTRA AND TOLERANCES (30 psig)

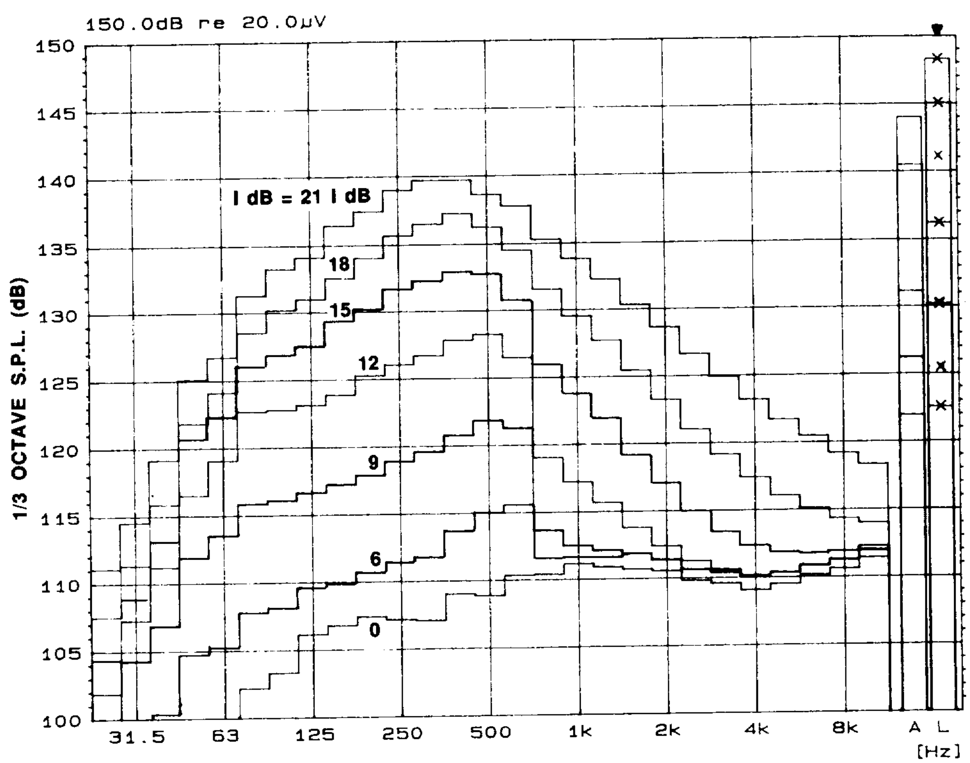

FIG. 4: VARIATION OF 1/3 OCTAVE S.P.L. SPECTRUM WITH DRIVE CURRENT (P = 30 psig)

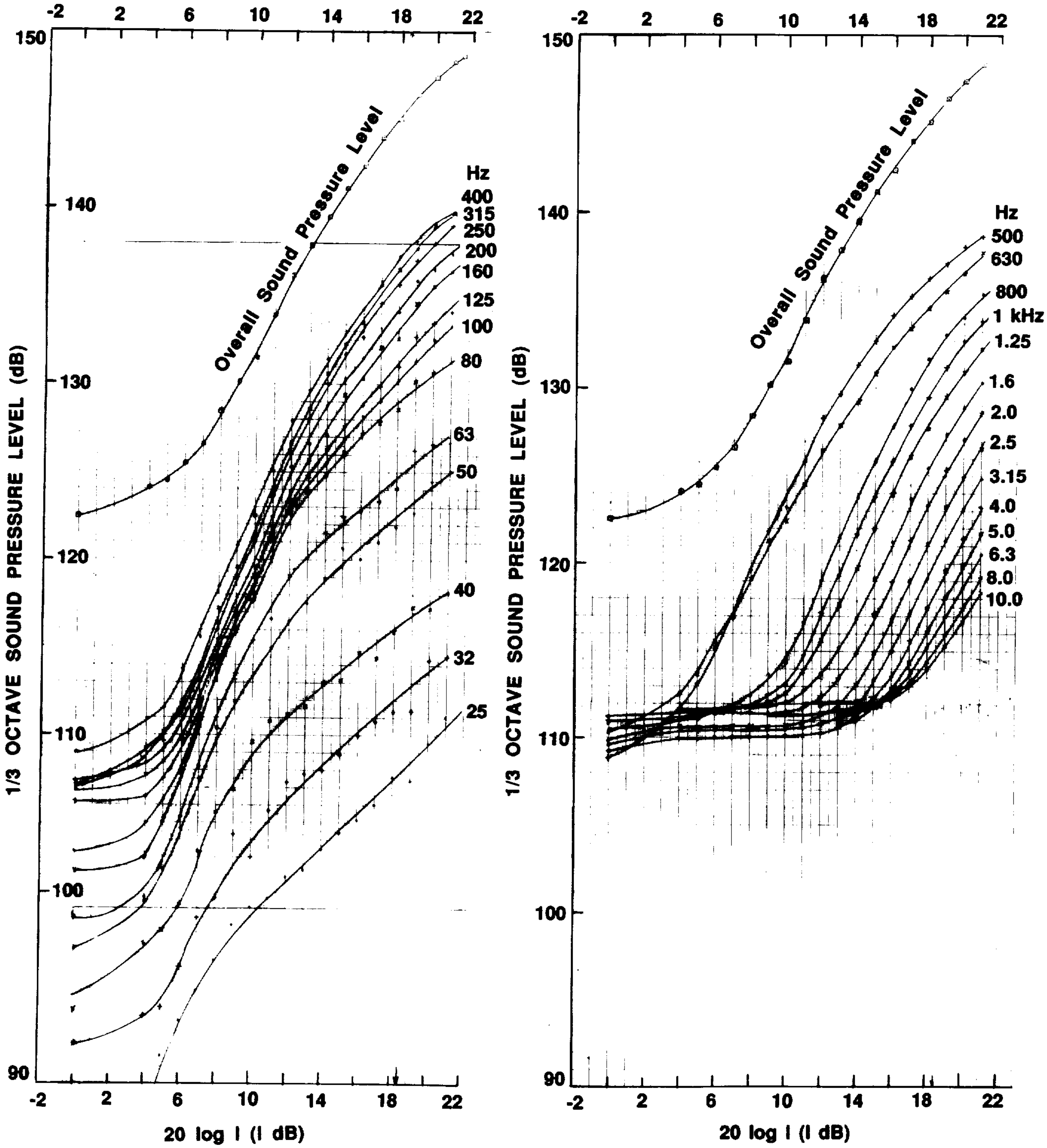

FIG. 5: 1/3 OCTAVE S.P.L. vs. DRIVE CURRENT (P = 30 psig)

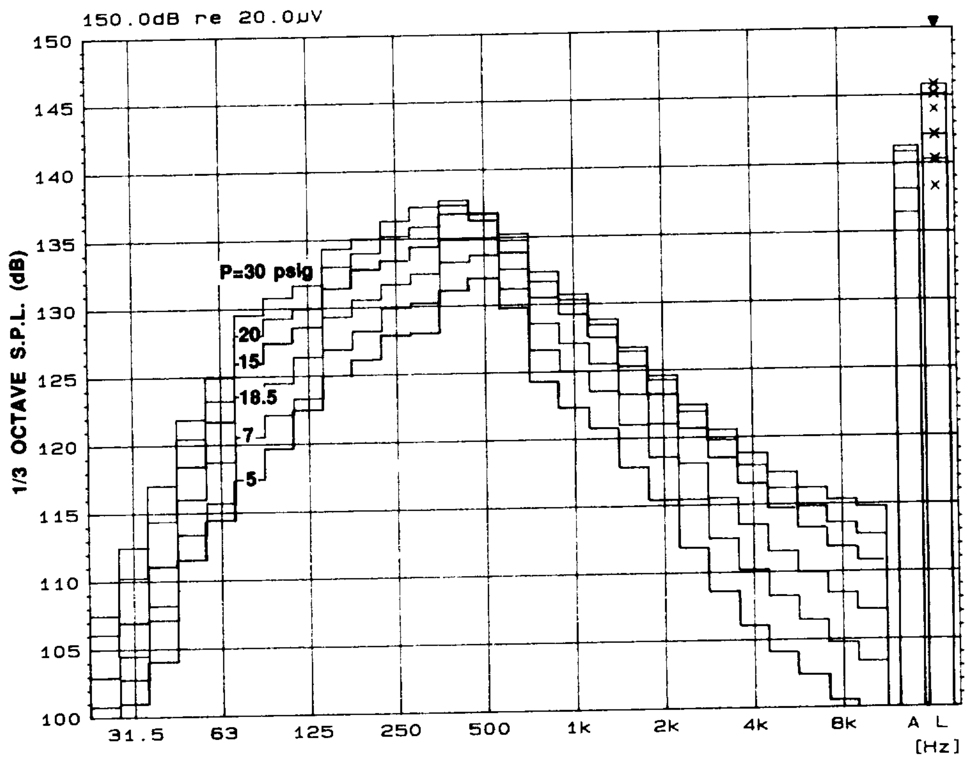

FIG. 6: VARIATION OF 1/3 OCTAVE S.P.L. WITH AIR PRESSURE (18.5 I dB)

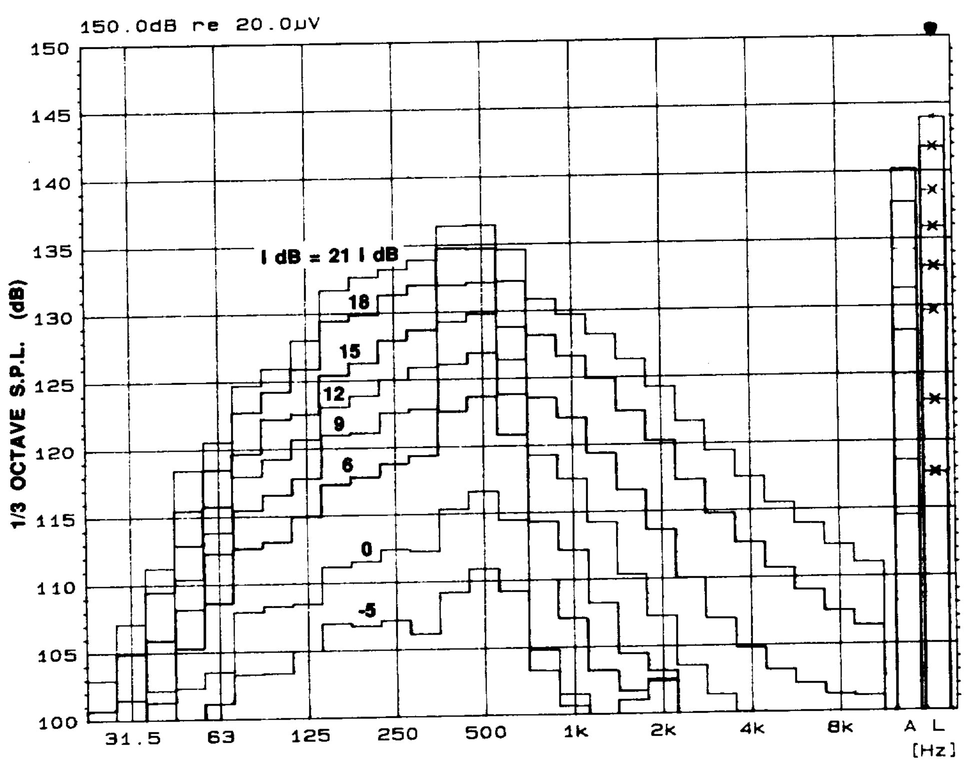

FIG. 7: VARIATION OF 1/3 OCTAVE S.P.L. WITH DRIVE CURRENT (P = 10 psig)

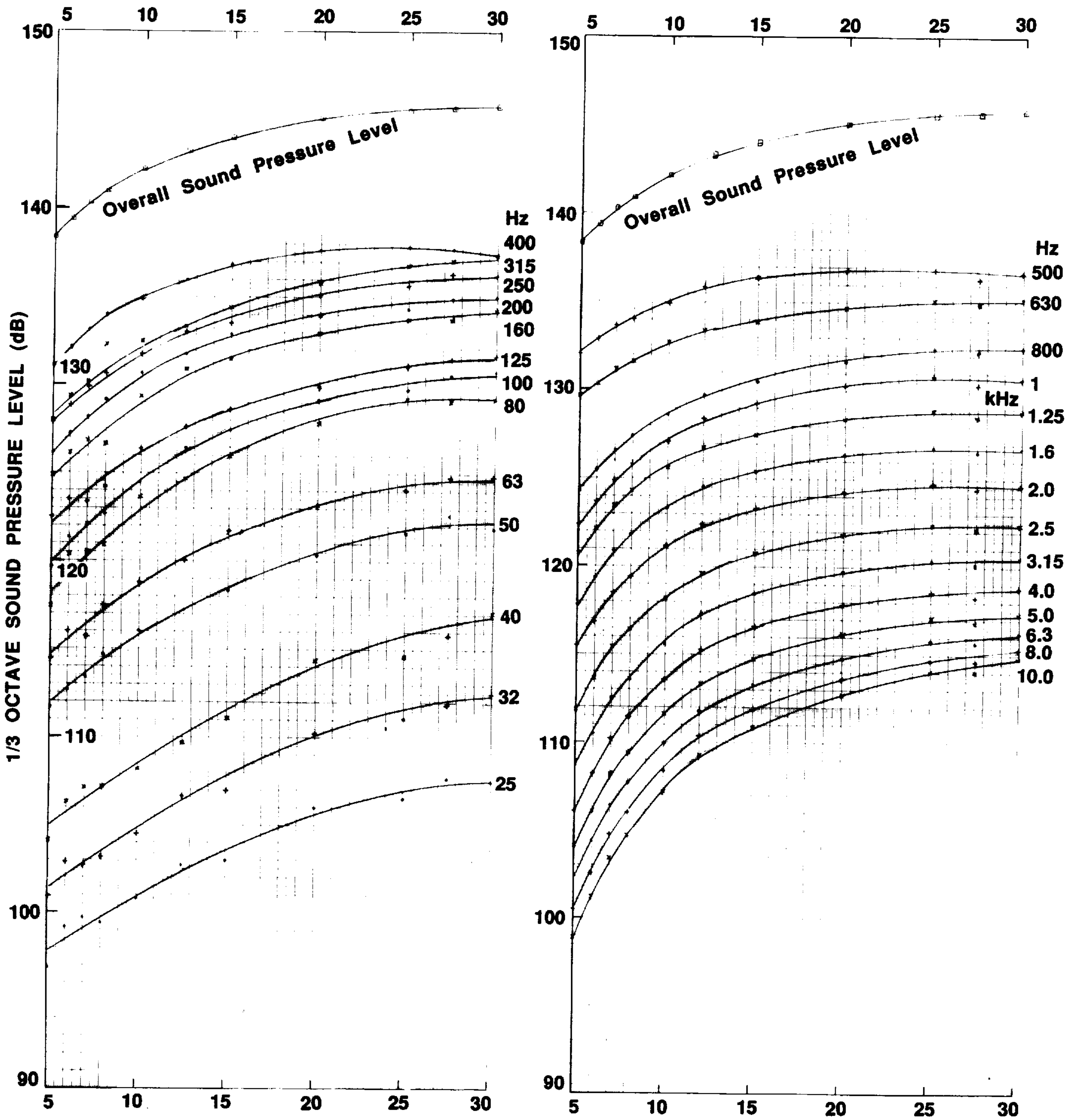

FIG. 8: 1/3 OCTAVE S.P.L. vs. AIR PRESSURE (I db = 18.5 dB)

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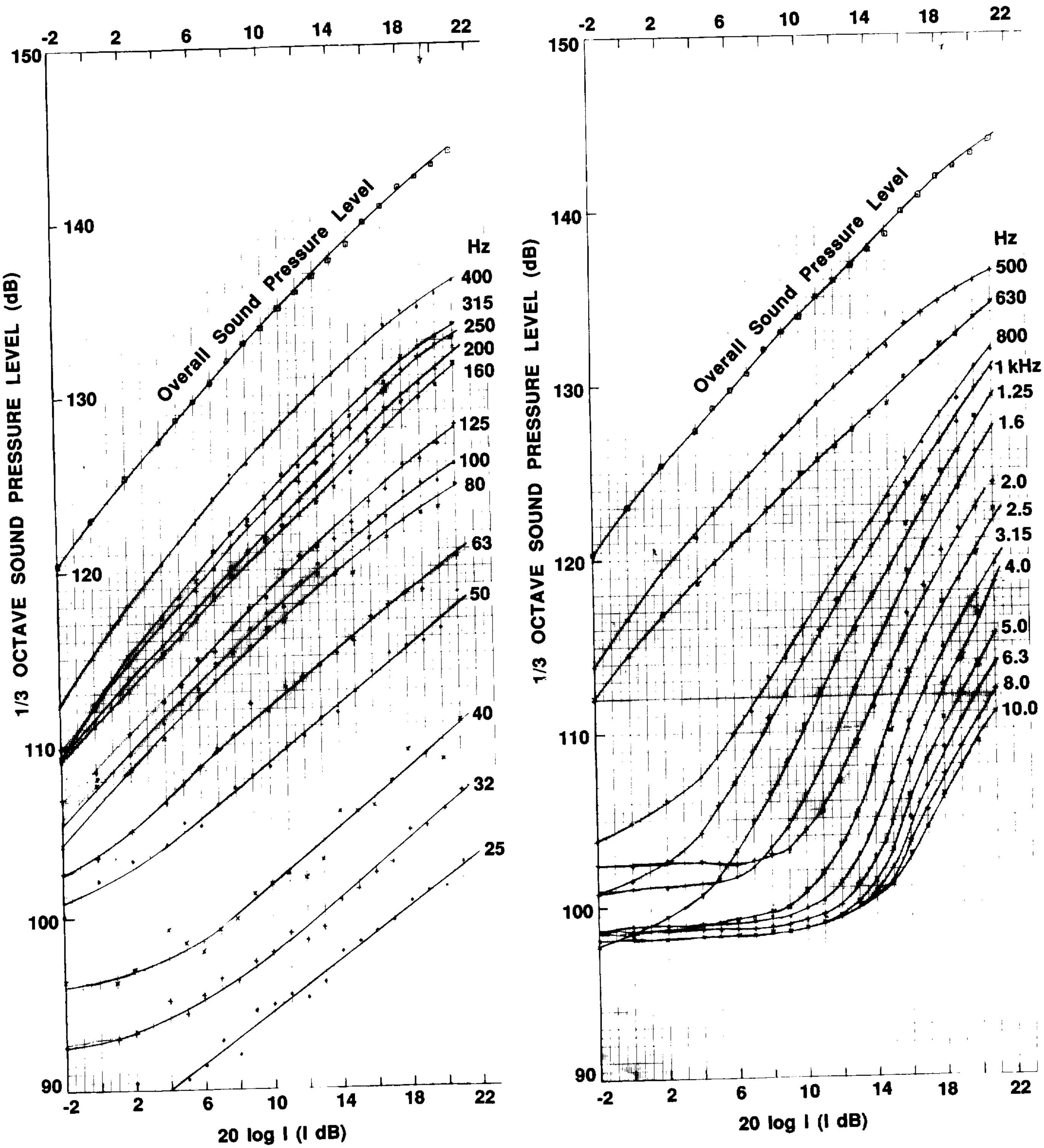

FIG. 9: 1/3 OCTAVE S.P.L. vs. DRIVE CURRENT (P = 10 psig)

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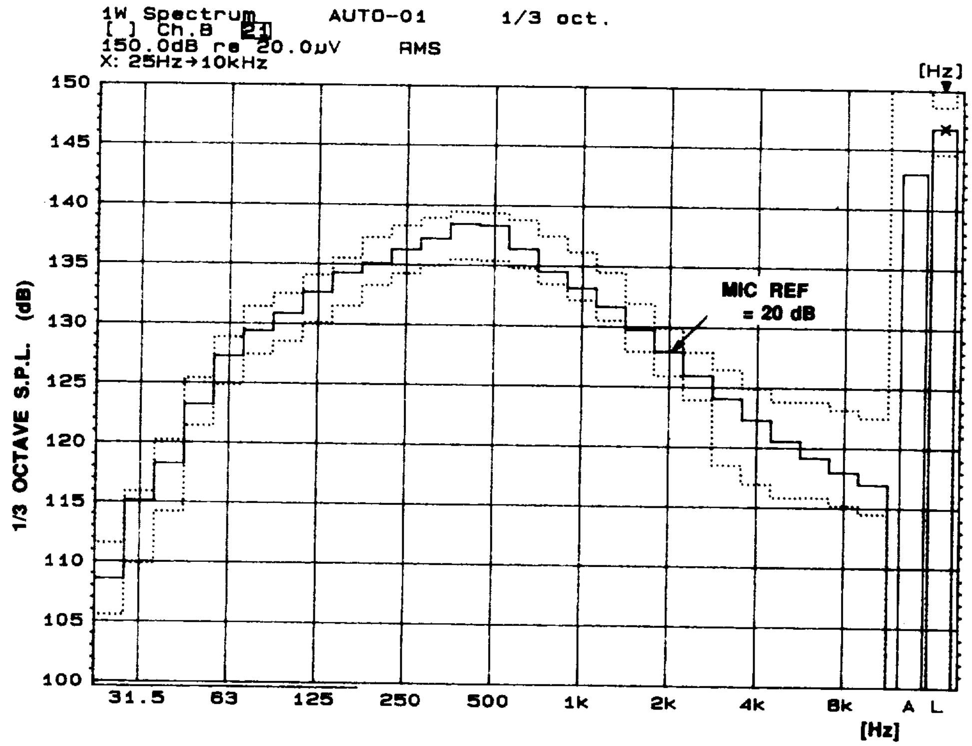


FIG. 10: QUALIFICATION SPECTRUM (AUTOMATIC CONTROL)
(P = 30 psig)

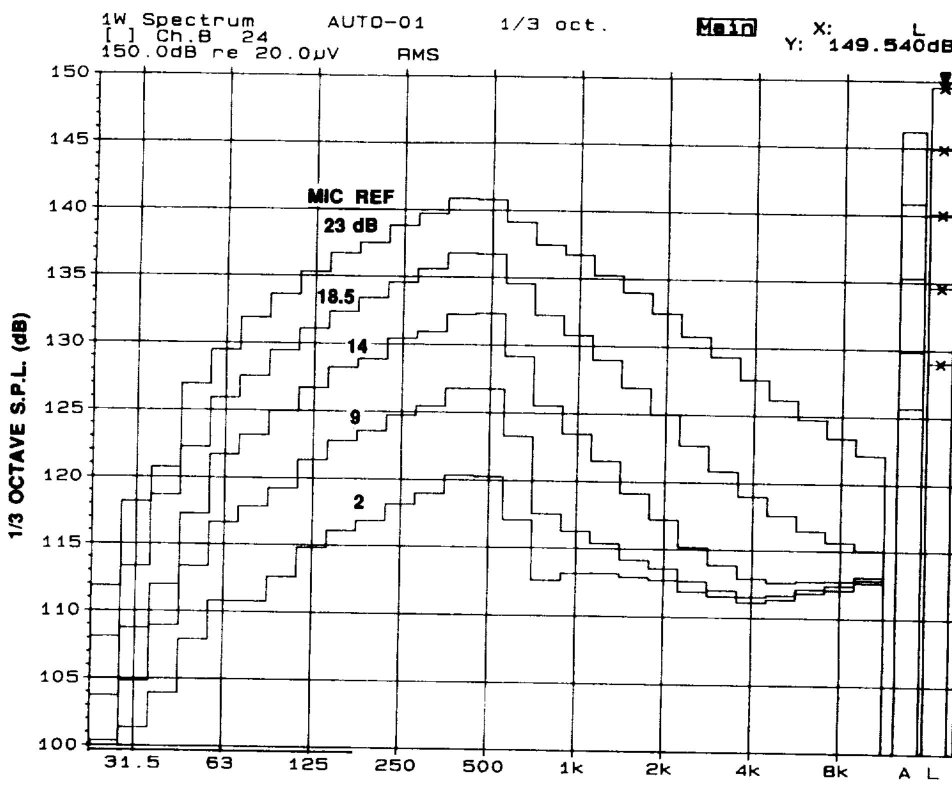
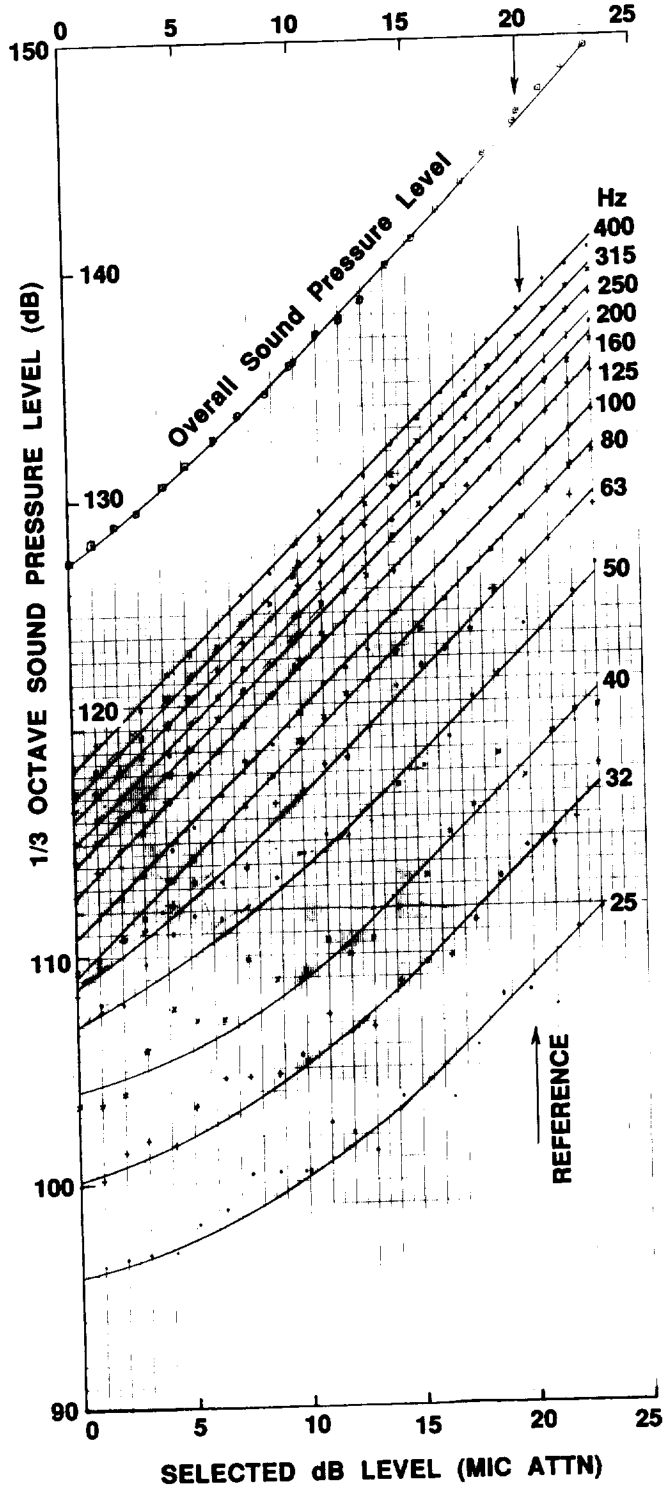


FIG. 11: PARALLEL SPECTRA (AUTOMATIC CONTROL)
(P = 30 psig)



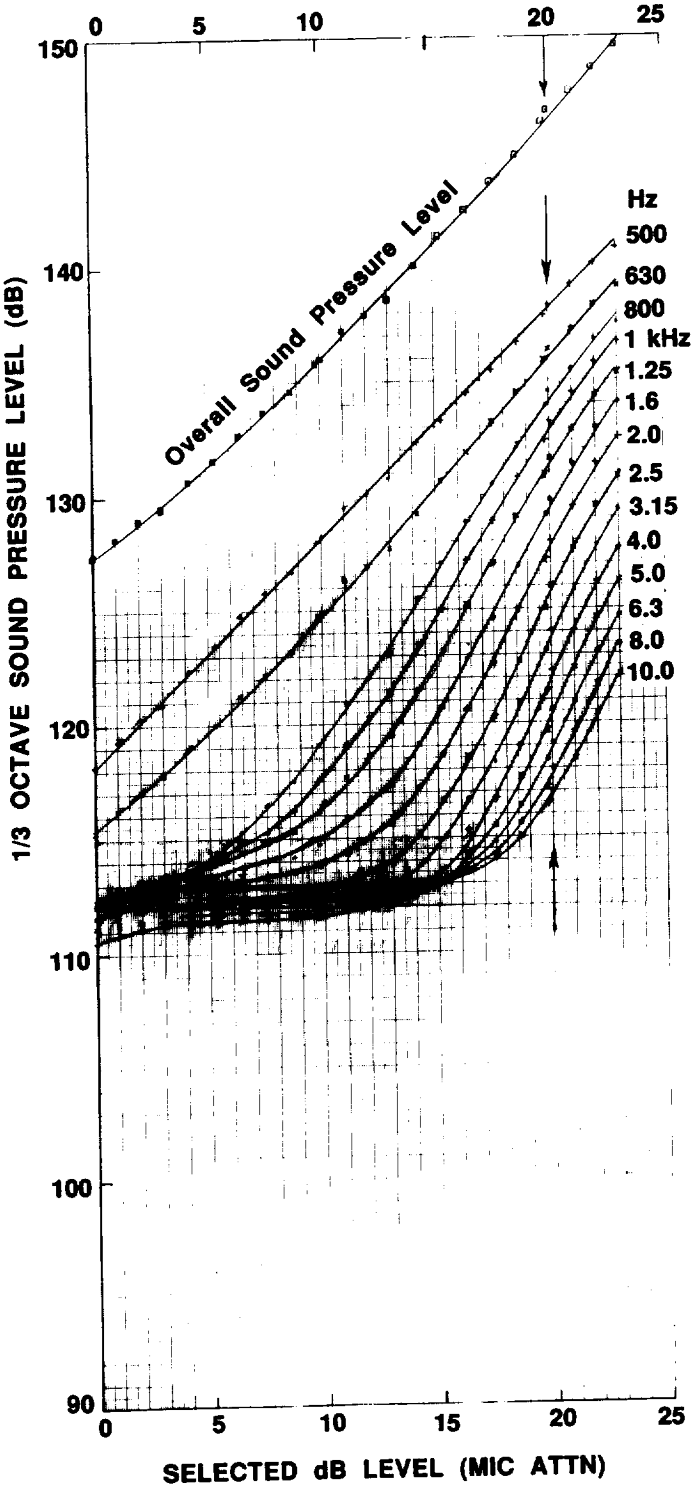


FIG. 12: 1/3 OCTAVE S.P.L. vs. SELECTED GAIN (AUTOMATIC CONTROL) PARALLEL SPECTRA

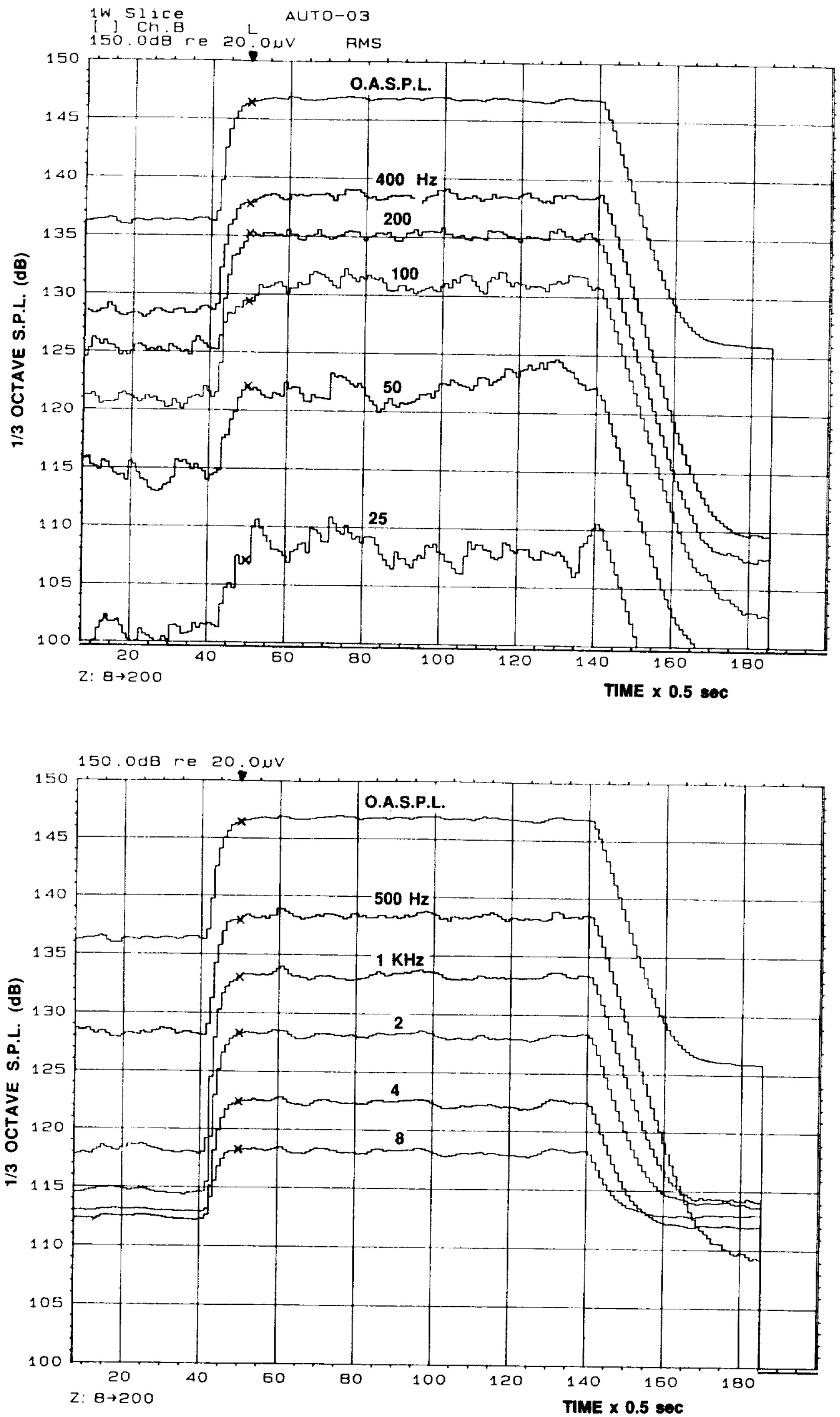


FIG. 13: QUALIFICATION TEST (AUTOMATIC CONTROL) (P = 30 psig) (20 sec at 136.6 dB; 45 sec at 146.6 dB)

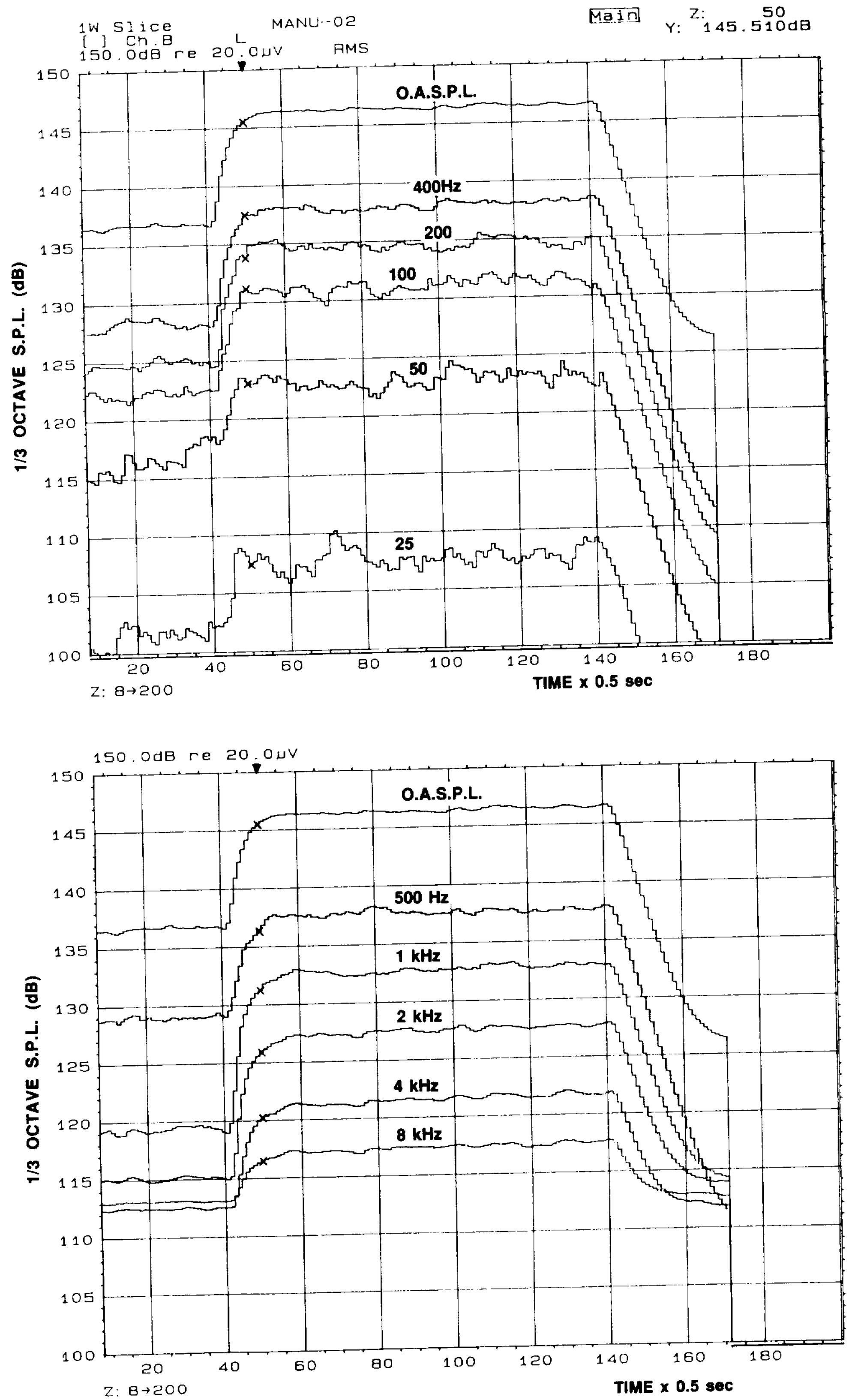


FIG. 14: QUALIFICATION TEST (MANUAL CONTROL) (P = 30 psig) (20 sec at 136.6 dB; 45 sec at 146.6 dB)

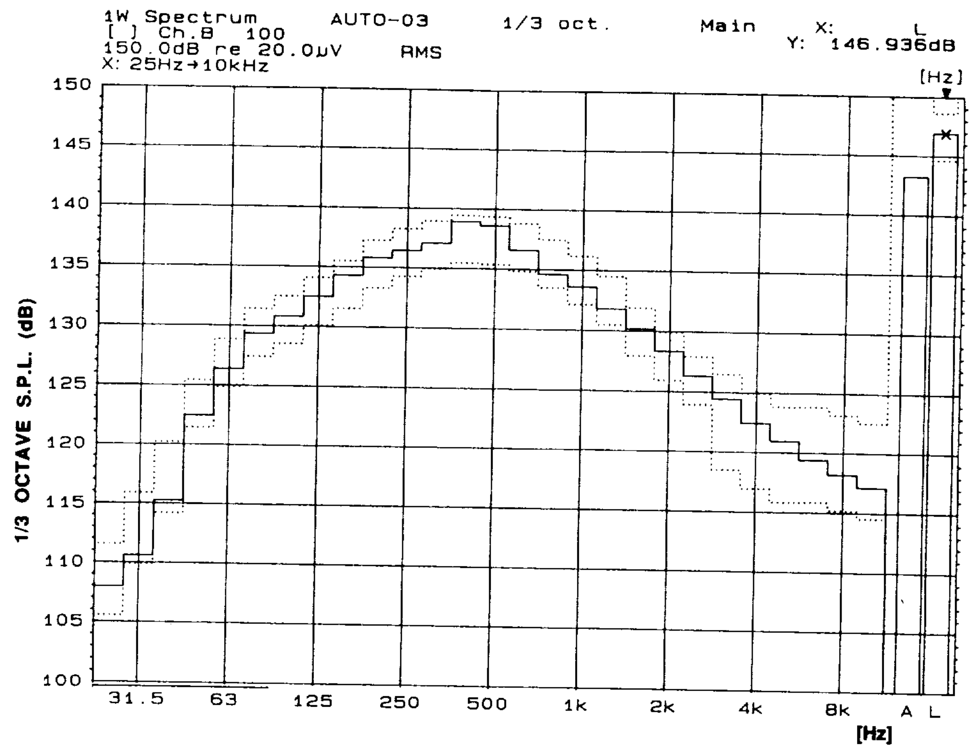


FIG. 15: QUALIFICATION TEST SPECTRUM (AUTOMATIC CONTROL) (P = 30 psig)

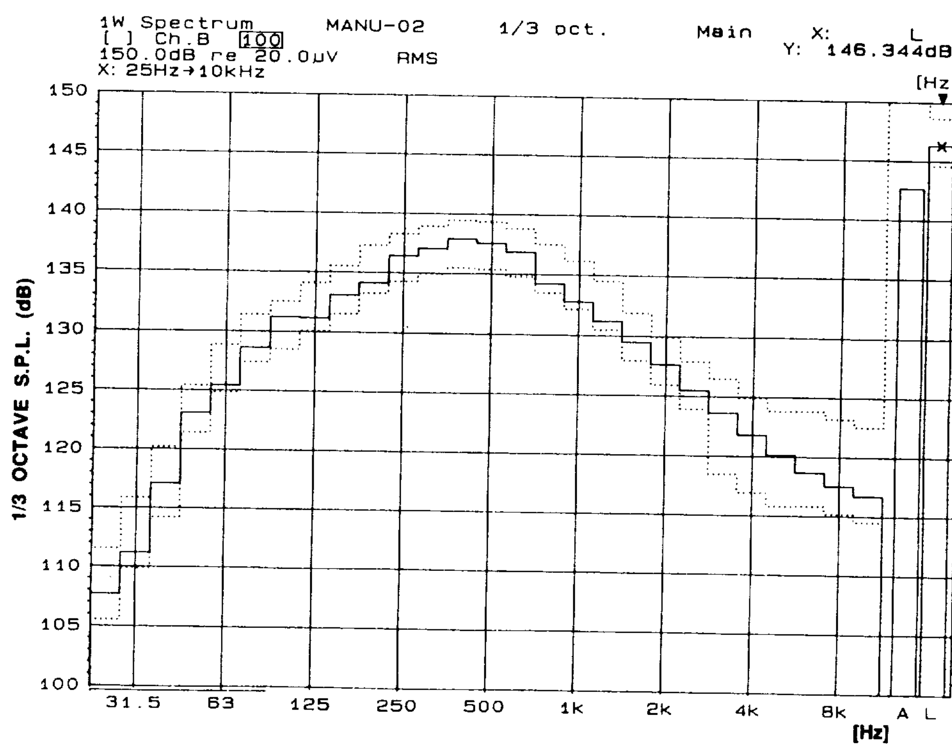


FIG. 16: QUALIFICATION TEST SPECTRUM (MANUAL CONTROL) (P = 30 psig)